EFFECTS OF URBANIZATION ON THE SALAMANDER
DESMOGNATHUS FUSCUS FUSCUS[1]

PAUL N. ORSER AND DONALD J. SHURE

Department of Biology, Emory University, Atlanta, Georgia 30322

Abstract. Five spring-fed streams near Atlanta, Georgia, comprise an urbanization gradient ranging from severely disturbed to undisturbed conditions. Population densities of the dusky salamander, *Desmognathus fuscus fuscus,* were estimated within these streams and were inversely proportional to the degree of urbanization. Differences in the chemical parameters among the stations, while reflecting habitat disruption, were not considered limiting factors on salamander densities. Analysis of invertebrate prey availability indicated no significant difference among the stations. Salamander populations were significantly affected by scouring caused by increased runoff and soil erosion in disturbed areas. Differences in salamander densities were also attributed to relative stability of the bank soils and availability and dispersal of protective cover. More cohesive substrates and increased availability of ground cover at the less disturbed areas offered greater stability against erosion and better habitats for salamander burrowing. Urbanization thus creates physical instability within stream habitats. Such instability results in a disruption of trophic structure by a reduction or loss of this major stream predator.

INTRODUCTION

The plethodontid salamanders have been the subject of life history (Wilder 1913, 1917, Dunn 1928, Pope 1924, Noble and Evans 1932, Hamilton 1932, Bishop and Chrisp 1933) and descriptive ecological studies (Hairston 1949). Recent attention has centered on the home range and activity (Harrison 1967, Barbour et al. 1969, Stewart and Bellis 1970), homing ability (Barthalamus and Bellis 1969, Rose 1966, Madison and Shoop 1970), population dynamics (Organ 1961, Spight 1967), and the evolutionary relationships (Tilley 1968) of this family, especially the genus *Desmognathus.* All such studies have taken place at sites removed from stream disturbances due to urbanization.

Desmognathus fuscus fuscus is a semiaquatic salamander which feeds primarily on small insects, spiders, isopods, centipedes, and oligochaetes (Barbour and Lancaster 1946, Hamilton 1932). *Desmognathus fuscus* is believed to be quite important in the trophic transfer or energy flow within many stream ecosystems (Hairston 1949, Spight 1967). This ecologically important species occurs in areas undergoing urban development and is, therefore, subject to changes in its environment due to urban influences.

This study describes the habitats of *D. fuscus* and compares several populations living under different degrees of urbanization or disturbance. Salamander densities were determined in streams subject to different degrees of urban influence. Correlations were then made between salamander densities and environmental factors including microenvironment, food

availability, and habitat stability in each stream habitat.

DESCRIPTION OF THE STUDY AREA

Five spring-fed streams were chosen to represent a gradient of urban influence ranging from severely disturbed to undisturbed conditions. Streams were selected according to proximity of homes and paved roads, presence of runoff ditches or drainage culverts, evidence of sand deposition, and absence of a natural vegetation canopy caused by land development. Sampling stations were selected at each stream based on comparability of stream flow rate and velocity, which are directly related to stream width, depth, and gradient of the stream bed.

The streams, located in the northeast sector of Atlanta, Georgia (Orser 1971), are geographically isolated from each other. One stream (E) receives runoff from paved surfaces and sustained severe impact during recent construction of two large buildings on the Emory University campus. Three stations (B-1, B-2, B-3) are located along Briarwillow Stream, which passes through the Echo Woods development site about 6 miles northeast of the Emory campus. Homes are situated along both sides of a wooded valley through which the stream passes. In addition to natural runoff, the stream receives runoff from paved surfaces. Stations B-2 and B-3 are more shaded than either stations B-1 or E since trees were removed for laying of pipelines and construction at the latter two sites. Two streams at Emory University's Lullwater Biological Field Station were selected as less disturbed habitats. Both streams flow through a large pine-hardwood forest within the field station. Although the two streams appear similar limnologically, L-1 receives some runoff from an unpaved road. The final stream (WW) is in a densely forested area near

Wesley Woods Methodist Home about 0.5 mile north-west of the Emory campus. The abundance of mosses and ferns and the dense cover of the forest canopy reflect the undisturbed nature of this area.

METHODS

Sampling grids were constructed in seven 10-m stream stations during June 1970. Maps were drawn for each station indicating the location and size of rocks, roots, leaf debris, or other potential cover for salamanders.

Salamander densities were estimated by a mark and recapture method (Hayne 1949). Four monthly population estimates were obtained at each station beginning in mid-July 1970. All estimates were conducted over an 8-day period. Each station was sampled four times over the 8-day period, with L-1, L-2, and WW sampled on alternate days from the remaining stations.

Salamanders captured during a thorough search of each station were measured (snout-vent length) and marked prior to release at the point of capture. Sub-adult (2.5 cm $\leq$ SV $\leq$ 3.5 cm) and adult (SV > 3.5 cm) salamanders were marked by toe-clipping with iridectomy scissors. Another marking system was necessary for juvenile salamanders (SV < 2.5 cm) since their digits were too small for accurate removal. A small section of the tail was clipped either at right angles to the anterior-posterior axis or in the transverse plane at either of two 45° angles. A different plane was used for each estimate. Both field observations and a laboratory study showed that juveniles from one estimate were distinguishable from those of another after 1 month's regeneration. Although tail clipping did not permit following individuals over the 4-month study, it allowed the inclusion of juveniles in the monthly population estimates.

Air and water temperature, dissolved oxygen, pH, and relative humidity were measured at each station for possible correlation with salamander densities. These parameters reflect the moisture-temperature complex which strongly influences salamander distribution (Hairston 1949). During each of five environmental studies, measurements were taken over 3 consecutive days at each station. All measurements were taken within a 2-hr period. Water pH was measured with an Analytical Measurements Pocket pH Meter. A Yellow Springs Oxygen Meter (Model 54) was used for determinations of air and water temperature and dissolved oxygen content. Relative humidity was measured with a Precision Relative Humidity Indicator (Bacharach Industrial Instrument Co.). Measurements of air temperature and relative humidity were made at ground level within 15 cm of the stream's edge. A pilot study showed extremely low coefficients of variation (0.0% $\leq$ CV $\leq$ 4.1%)

for five measurements of each parameter at each station (Orser 1971). A single measurement of each parameter was subsequently taken at each station.

The food source of *D. fuscus* was analyzed to determine any influence of urban effects on feeding preferences. Salamanders captured along the stream within 5 m of a station were collected for analysis of stomach contents. Analysis was not performed on salamanders from stations B-1, B-2, or E due to low densities. Stomachs of live animals were irrigated by inserting, orally, a small-bore tube fitted over the blunted needle of a 10-cc syringe. Distilled water was slowly forced into the stomach as the tube was withdrawn from the esophagus (Merchant 1970). Stomach contents were regurgiated through this process, then frozen for later examination. A pilot study indicated all stomach contents were removed by this method. Animals were returned unharmed to their points of capture after a 24-hr observation period.

The abundance and diversity of potential prey species were compared in each station as a measure of food availability. Invertebrate populations were sampled at four randomly selected sites within each station. A 0.25 m² wooden quadrat frame was placed on the stream bank with one-quarter of its area extending into the stream proper. Invertebrates were removed by hand from the leaf cover and within the upper 5.0 cm of soil and placed into collecting jars containing 70% alcohol for later examination.

Factors indicating the physical stability of the streams and surrounding areas were also studied. The current velocity and volume of flow were determined for each station under normal and accelerated flow conditions with a glass Pitot tube. Measurements of stream width and depth were taken as suggested by Welch (1948). A water sample was collected from physically comparable sites at each station during a steady rain for comparison of suspended particulate material. Three 100-ml fractions of each sample were filtered by Millipore filtration. The dried and pre-weighed filters were then oven dried at 100°C for 24 hr and reweighed to determine the mg/liter of suspended particulate material. Measurements of the stream bank soil particle size were conducted to determine the relative stability of the bank soils against erosion. Soil composition was determined by the soil hydrometer method of mechanical analysis (Bouyoucos 1927). Five 50-g dry weight samples were analyzed for each station.

Availability of protective cover was also determined at each station. The area occupied by rocks, root mats, and miscellaneous debris was calculated for both the stream channel and the combined channel and bank at each station. The total area for each station was determined, and the percentages of that total area occupied by stream and channel-bank cover were calculated.

RESULTS

Desmognathus fuscus was the most abundant salamander species in the areas studied. Two *Eurycea bislineata* were recorded at stations B-1, L-1, and L-2. A single *Pseudotriton ruber* each was observed
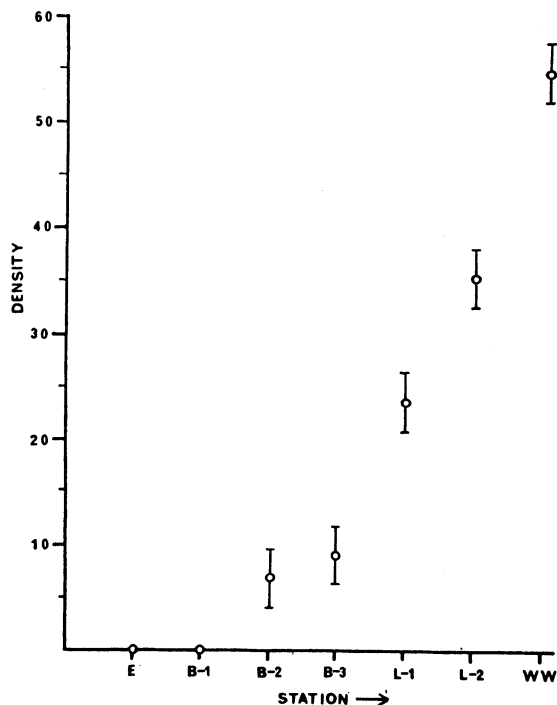

FIG. 1. Salamander density along the disturbance gradient. Arrow indicates decreasing degree of disturbance. Intervals represent a graphic extension ($\bar{x} \pm$ LSD/2) of the least significant difference and are plotted at the .05 level.

TABLE 1. Analysis of variance of salamander density over time at each station

Source of variation	df	S.S.	M.S.	F
Among stations	6	10117.4	1686.2	114.8**
Among times	3	83.1	27.7	1.9
Error	18	264.4	14.7	
Total	27	10464.9		

**Significant at .01 level.

at stations L-1 and B-3. Only *D. fuscus* was included in the density estimates.

Desmognathus densities varied in the streams, ranging from zero to nearly 60 individuals per 10-m station (Fig. 1). The population densities were significantly different (Table 1) among the stations; however, there was no significant difference over time at any station. All further statistical comparisons involving salamander densities therefore used the mean density value ($N = 4$) for each station.

The differences in salamander densities were closely correlated with the degree of urbanization or disturbance in each area (Fig. 1). Salamanders were absent from the severely disturbed stations at Emory and B-1. Densities were low at the remaining Briarwillow stations, while the two Lullwater streams contained relatively high densities of salamanders. The stream at Wesley Woods, showing the least distrubed condition, contained the highest density of salamanders.

A definite correlation existed between salamander densities and changes in stream size, current velocity, and volume of flow during rainfall (Table 2). The more disturbed stations at Briarwillow Stream had the greatest increase in stream width, current velocity, and volume of stream flow. The more natural streams at Lullwater and Wesley Woods exhibited much less change in these parameters. Changes in stream depth showed little relation to salamander densities at each station.

The amount of sediment carried by the water during rainfall was closely related to changes in the current velocity and volume of flow along the disturbance gradient. The amount of suspended particulate material occurring at each station during rainfall was significantly different ($F = 17.877$, $P < .01$) when tested by analysis of variance. Analysis of variance for regression on these data indicated a significant ($F = 6.954$, $P < .05$) inverse relationship between salamander densities and suspended particulate material along the disturbance gradient. (Fig. 2).

A strong relationship also existed between salamander density and soil particle size of the stream

TABLE 2. Changes in stream width ($N = 10$), depth ($N = 4$), current velocity, and volume of flow at each station during steady rainfall. $\triangle X$ = accelerated condition–normal condition

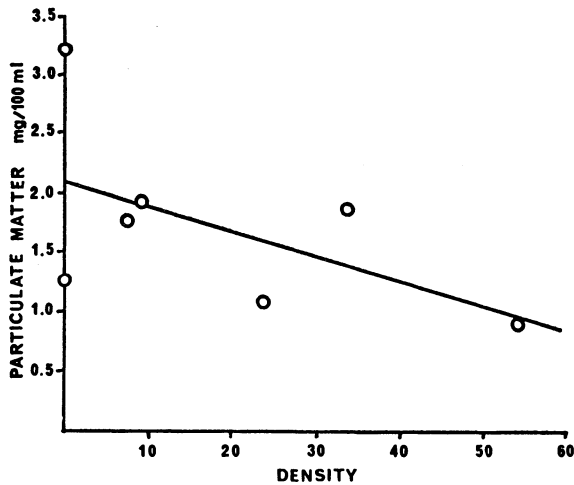| Station	Width (cm)		Depth (cm)		Current velocity (ft/sec)		Volume of flow (ft³/sec)	
	Normal	$\triangle X$	Normal	$\triangle X$	Normal	$\triangle X$	Normal	$\triangle X$
E	91.44	30.48	2.89	1.02	1.34	0.28	0.303	0.365
B–1	60.96	30.48	1.87	1.71	1.10	0.93	0.122	0.333
B–2	100.58	74.68	3.22	2.92	1.34	0.80	0.372	0.944
B–3	64.00	51.82	2.18	1.40	0.78	0.79	0.092	0.466
L–1	67.05	27.43	2.69	0.86	1.34	0.15	0.209	0.218
L–2	48.76	27.44	1.39	2.01	1.34	2.01	0.076	0.269
WW	60.96	15.24	1.72	1.22	1.10	0.28	0.098	0.167

FIG. 2. Regression of suspended particulate material and mean salamander density ($N = 4$). The slope ($b = -0.020$) is significant at the .05 level.
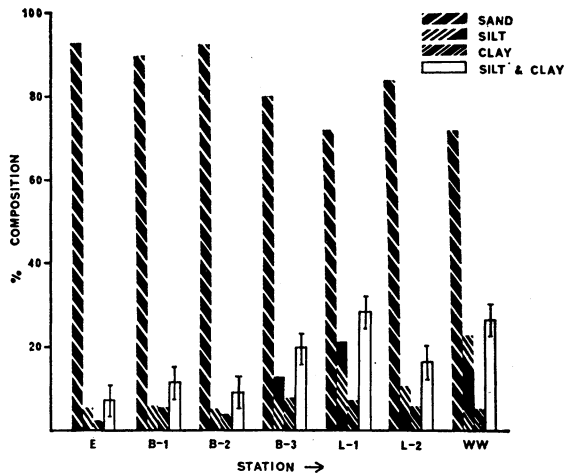

FIG. 3. Soil composition of the stream bank at each station. Arrow indicates the decreasing degree of disturbance. Each histogram represents the mean of five samples. Open histograms represent the summation of the means of the combined silt and clay fractions. Intervals represent a graphic extension of the least significant difference plotted at the .05 level.

banks (Fig. 3). The sand fraction generally decreased while the silt and clay fractions increased with decreasing urbanization. More striking, however, was the significant increase ($F = 9.173$, $P < .01$) in the combined silt-clay fraction along the gradient. Both silt-clay fraction and salamander density increased as the degree of disturbance decreased.

Salamander densities were directly related to the total available protective cover in each station (Fig. 4). Stations located in the more disturbed areas had little or no protective cover within the stream or along the bank. These stations also maintained the lowest population densities. Salamander density in-
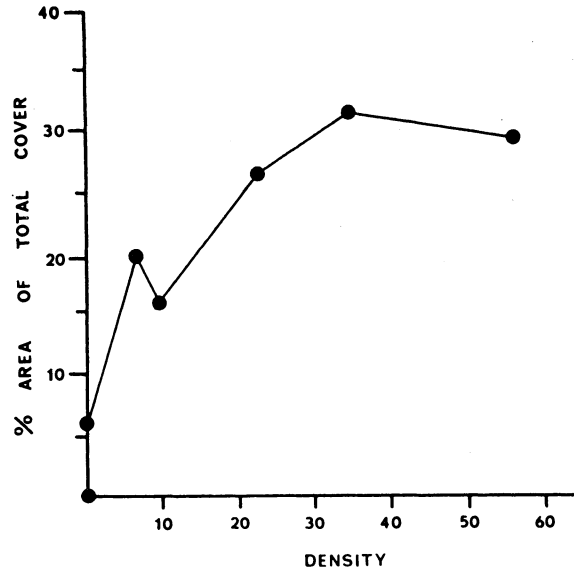

FIG. 4. Comparison of mean salamander density and available ground cover at each station. Data represent percentage of station area occupied by rocks, root mats, and debris.
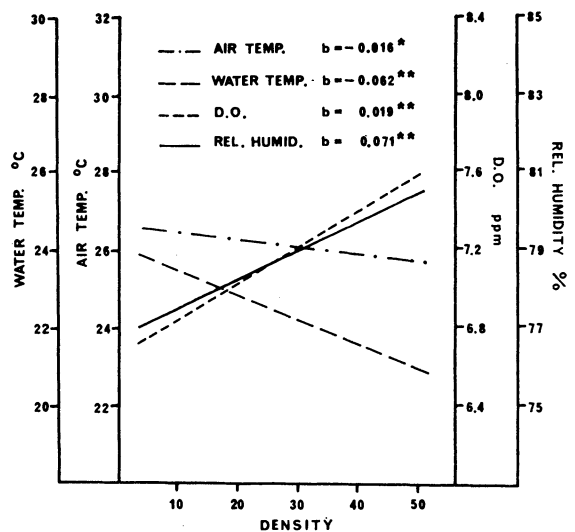

FIG. 5. Comparison of environmental parameters along a salamander density gradient. Data show changes during a representative period of afternoon measurements (September 2–4, 1970). Slopes and their level of significance (* = .05, ** = .01) are included for each parameter.

creased with the greater availability of total cover in more natural areas.

Regression analysis was used to express relationships between environmental parameters and salamander densities along the disturbance gradient (Fig. 5). Regression lines were fitted according to linear analysis for a bivariate distribution. Each slope was tested for significance by analysis of variance for regression. The coefficient of determination (r^2) was
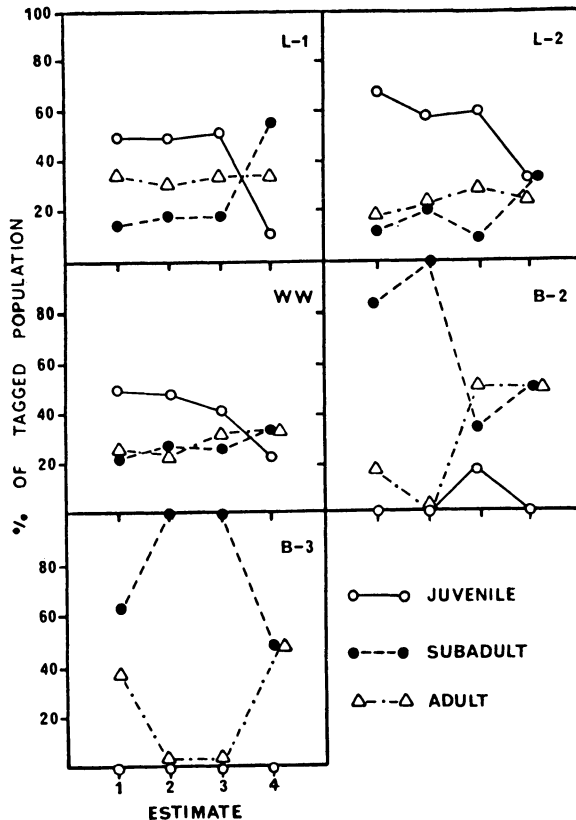
Fig. 6. Changes in age distribution of salamander populations at five stations from July through October 1970.

station. The Shannon estimates were tested for significant difference (Hutcheson 1970) using analysis of variance. No significant difference in invertebrate diversity resulted $(F = 1.626, P > .05)$ among stations. The mean number of invertebrates at each station was also not significant $(F = 2.414, P > .05)$. Availability of potential prey was therefore not considered a limiting factor for salamander populations living under different degrees of urban disturbance. The analysis of salamander stomach contents indicated that a variety of invertebrate prey was utilized by *D. fuscus* (Orser 1971). This analysis reflected the nonspecific feeding habits of this species.

DISCUSSION

Several interacting factors have produced an inverse relationship between salamander density and the degree of environmental disturbance in the streams studied. Salamander density is closely related to events causing and resulting from soil erosion. Rainfall and subsequent runoff from denuded land results in greater current velocity and volume of flow in more urbanized stream habitats. Much erosion of both the stream channel and bank results from this process.

The causes of these changes in stream morphology are evident at the more urbanized stations. Considerable runoff from paved surfaces in the Briarwillow area enters the stream via concrete conduits. Ditches directing runoff into the stream from areas adjacent to homes are also abundant in the area. The removal of trees for construction in the Briarwillow area has resulted in decreased stability of the soils against erosion. Many trees have also been undercut by the increased stream flow and have subsequently fallen. Increased volumes of water thus rush downstream during rainfall, undercut the bank, and widen the stream channel. The Emory stream shows a similar effect of increased runoff from paved surfaces and the instability of surrounding soils caused by construction and tree removal. Sporadic addition of chemical pollutants to the more urbanized streams may also contribute to the mortality of resident organisms. At Lullwater and Wesley Woods, however, the abundance of trees provides a dense canopy and a stabilizing, water-absorbing root system which reduces runoff to a minimum. Changes in velocity and volume of flow of urban streams are greatest during heavy, localized showers. Resulting scouring by a wall of turbulent water is likewise most detrimental to stream and bank-dwelling organisms. Salamander density appears to be closely related to the magnitude of runoff along the urbanization gradient. Large volumes of water in the more urbanized streams create instability within the stream and result in a physical disruption of salamander populations.

calculated where significant slopes existed. The slopes for water temperature, dissolved oxygen, and relative humidity versus salamander density were consistent in sign throughout the experiment (Orser 1971). Water temperature generally decreased while dissolved oxygen and relative humidity increased as the degree of disturbance decreased. In no case was the slope for pH significant at the 0.05 level.

Changes in the age distribution of salamanders were similar at the less urbanized stations (L-1, L-2, and WW) (Fig. 6). Juveniles initially formed the largest fraction of the total population. They decreased proportionally from July to October as the subadult portion increased during this period. The fraction of adults in each area remained unchanged over the study period. These trends suggest that a fairly stable population was present in these undisturbed areas. No discernible patterns appeared at the disturbed stations where the changes in subadult and adult fractions of the populations were irregular and few, if any, juveniles were present.

The number and diversity of invertebrates were similar along the urbanization gradient. The Shannon information formula (Pielou 1966), $H' = -\Sigma p_i \log p_i$, was applied to the quadrat sampling data $(N = 4)$ to estimate mean species diversity at each

Greater runoff increases the erosion of soil from stream banks and adjacent areas. The greater amount of suspended particulate material in the water during rainfall and the high sand content in the bank soils at urbanized stations reflect the erosion of soil from stream banks and surrounding areas. Less erosion was evident in the more natural areas. The significantly higher silt-clay fractions and lower suspended particulate material at the more natural stations suggest cohesiveness of the soils. The physical stability of the soils against erosion and for burrowing purposes thus appears important to the establishment and maintenance of larger salamander densities.

Increased runoff and greater erosion lead to physical scouring of the stream channel. Scouring, which results in the removal of leaves, stones, gravel, debris, and resident organisms, was quite important in an intermittent stream in Ohio (Stehr and Branson 1938). At the more urbanized streams, flooding occurs throughout the year with resultant low salamander densities. Scouring removes adult and juvenile salamanders making population re-establishment difficult. In contrast, the less disturbed streams offer a more stable physical condition with larger and more stable salamander populations present.

The availability of ground cover is also directly related to salamander densities. Cover, which affords protection against desiccation and predation, and enables establishment of home burrows (Wilder 1913, Stewart and Bellis 1970), is sparse at the more disturbed stream stations. The increased runoff and erosion in these areas has resulted in the removal of most stream cover. In contrast, the less disturbed stations have more available cover. Cover thus provides protection and home sites for resident organisms in natural areas.

A subtle relationship exists between salamander density and changes in temperature, dissolved oxygen, and relative humidity along the disturbance gradient. The differences in these parameters reflected changes in the tree and understory canopies along the gradient. Total canopy cover increases from disturbed to undisturbed stream areas. Air temperature and water temperature decrease, and the dissolved oxygen and relative humidity increase in response to the increased shade along the gradient. Moisture and temperature strongly affect the distribution of salamander species (Hairston 1949, Organ 1961) as well as their periods of activity (Wilder 1913, Barbour et al. 1969). These environmental factors, however, are not considered limiting to salamander densities in this study because of the restricted range of values recorded for each parameter along the gradient. Instead, these factors reflect slight microenvironmental changes caused by disruption of the natural vegetation

Changes in the age distribution of salamanders at Lullwater and Wesley Woods reflect changes that might be expected in nonstressed habitats. The decreasing numbers of juveniles and increasing numbers of subadults are largely attributed to growth over the study period. The decrease in juveniles may also be due to rain, predation, or greater concealment of newly hatched larvae. Changes in the age distribution of salamander populations at Briarwillow are erratic. Different individuals were present at each population estimate, and the proportions of the juveniles, subadults, and adults changed between estimates. The instability of these populations is attributed to the scouring effect of increased volumes of water (Stehr and Branson 1938, Momot 1966) as well as the paucity of suitable protective cover.

The invertebrate studies indicate that salamander densities in the more disturbed stations are not depressed by the absence of specific prey species or their numbers. Conversely, the densities at the more natural habitats are not enhanced by greater numbers or diversity of prey. These observations agree with those of Hamilton (1932), Barbour and Lancaster (1946), and Hairston (1949), who have recorded the generalized carnivorous feeding habits of dusky salamanders.

Increasing pressures are thus being exerted on salamander populations by the multiple effects of urbanization. The scouring of flood waters and its influence on the availability of protective ground cover are results of the removal of vegetation from surrounding areas. Flooding of a stream channel and the resulting scouring and disruption of the stream bed are apparently reducing or eliminating salamander populations in many urban areas. Populations at less urbanized areas are generally removed from these pressures with higher and more stable salamander densities present.

Continuing urbanization in many areas will thus result in the increased disturbance of many stream habitats. One consequence will be the reduction or total loss of salamander populations from these areas. The loss of a major predator and the physical instability in these streams will lead to serious alterations in the trophic relationships that now exist in many small stream ecosystems.

LITERATURE CITED

Barbour, R. W., J. W. Hardin, J. P. Shafer, and M. J. Harvey. 1969. Home range, movements, and activity

of the dusky salamander, *Desmognathus fuscus*. Copeia **1969**: 293–297.

Barbour, R. W., and L. Y. Lancaster. 1946. Food habits of *Desmognathus fuscus* in Kentucky. Copeia **1946**: 48–49.

Barthalamus, G. T., and E. D. Bellis. 1969. Homing in the northern dusky salamander, *Desmognathus fuscus fuscus* (Rafinesque). Copeia **1969**: 148–153.

Bishop, S. C., and H. P. Chrisp. 1933. The nests and young of the Allegheny salamander, *Desmognathus fuscus ochrophaeus* (Cope.) Copeia **1933**: 194–198.

Bouyoucos, G. 1927. The hydrometer as a new method for the mechanical analysis of soils. Soil Sci. **23**: 343–353.

Dunn, E. R. 1928. The habitats of Plethodontidae. Am. Nat. **62**: 236–248.

Hairston, N. G. 1949. The local distribution and ecology of the plethodontid salamanders of the Southern Appalachians. Ecol. Monogr. **19**: 47–73.

Hamilton, W. J. 1932. The food and feeding habits of some eastern salamanders. Copeia **1932**: 83–86.

Harrison, J. R. 1967. Observations of the life history, ecology, and distribution of *Desmognathus aeneus aeneus* Brown and Bishop. Am. Midl. Nat. **77**: 356–370.

Hayne, D. W. 1949. Two methods for estimating populations from trapping records. J. Mammal. **30**: 157–162.

Hutcheson, K. 1970. A test for comparing diversities based on the Shannon formula. J. Theor. Biol. **29**: 151–154.

Madison, D. M., and R. C. Shoop. 1970. Homing behavior, orientation, and home range of salamanders tagged with Tantalum-182. Science **168**: 1484–1486.

Merchant, H. C. 1970. Estimated energy budget of the red-backed salamander, *Plethodon cinereus*. Ph.D. Thesis. Rutgers University, New Brunswick, N. J. 105 p.

Momot, W. T. 1966. Upstream movement of crayfish in an intermittent Oklahoma stream. Am. Midl. Nat. **75**: 150–159.

Noble, G. K., and G. Evans. 1932. Observations and experiments on the life history of the salamander, *Desmognathus fuscus* (Rafinesque). Am. Mus. Novit. **533**: 1–16.

Organ, J. A. 1961. Studies of the local distribution, life history, and population dynamics of the salamander genus *Desmognathus* in Virginia. Ecol. Monogr. **31**: 189–220.

Orser, P. N. 1971. The effects of urbanization on the salamander, *Desmognathus fuscus fuscus*. M.S. Thesis, Emory University, Atlanta, Ga. 60 p.

Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. **13**: 131–144.

Pope, C. H. 1924. Notes on North Carolina salamanders with especial references to the egg laying habits of *Leurognathus* and *Desmognathus*. Am. Mus. Novit. **153**: 1–15.

Rose, F. L. 1966. Homing to nests by the salamander *Desmognathus auriculatus*. Copeia **1966**: 251–253.

Spight, T. M. 1967. Population structure and biomass production by a stream salamander. Am. Midl. Nat. **78**: 437–447.

Stehr, W. C., and J. W. Branson. 1938. An ecological study of an intermittent stream. Ecology **19**: 294–310.

Stewart, G. D., and E. D. Bellis. 1970. Dispersion patterns of salamanders along a brook. Copeia **1970**: 86–89.

Tilley, S. G. 1968. Size-fecundity relationships and their evolutionary implications in five desmognathine salamanders. Evolution **22**: 806–816.

Welch, P. S. 1948. Limnological methods. Blakiston Co., Philadelphia. 381 p.

Wilder, I. W. 1913. The life history of *Desmognathus fusca*. Biol. Bull. **24**: 251–342.

———. 1917. On the breeding habits of *Desmognathus fusca*. Biol. Bull. **32**: 13–20.